

APPENDIX C

EXAMPLES OF RELIABILITY PREDICTION METHODS

C-1. Introduction

The following examples of reliability prediction methods have been simplified by omitting some mathematical constraints. For example, it is assumed that the elements are independent (that is, if the failure of one has no effect on another). The examples, however, are valid and should give the reader a feeling for the process of combinatorial reliability calculations.

C-2. Failure rate example

Figure C-1 shows a series system with four independent parts. The failure rate, λ_i , of each part is indicated below the element. The failure rate of this series system, λ_{System} , is equal to the sum of the individual failure rates (the mean time to failure is the inverse of the failure rate):

$$\begin{aligned}\lambda_{System} &= \lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 \\ &= 10.1 + 5.6 + 1.1 + 15.5 \\ &= 32.3 \text{ (failures per million operating hours)}\end{aligned}$$

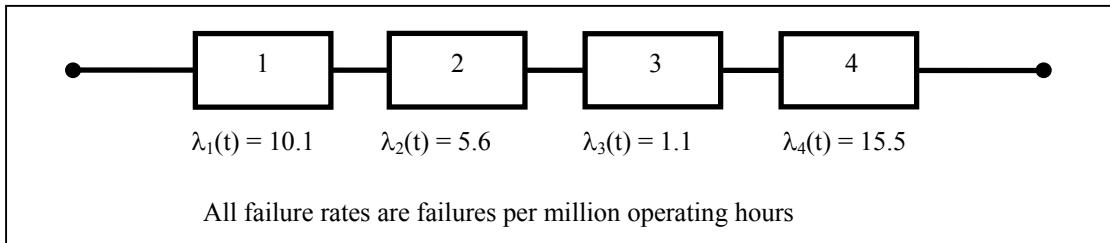


Figure C-1. The failure rate of this series system is $\lambda_{System} = 32.3$ failures per million operating hours. The mean time to failure is $1/\lambda_{System} = 30,960$ hours.

C-3. Similarity analysis

A new system being developed will consist of a signal processor, a power supply, a receiver transmitter, and an antenna, all in a series configuration. The antenna and power supply are off-the-shelf items that are used in a current system. The reliability of each of these items for an operating period of 150 hours is 0.98 and 0.92, respectively. The signal processor will be a new design incorporating new technologies expected to provide a 20% improvement over previous signal processors. The prior generation of signal processors has exhibited failure rates ranging from 1 to 3 failures per 10,000 operating hours. The receiver transmitter is a slightly modified version of an existing unit that has achieved an MTBF of 5,000 hours for the past year. The new system will be used in a slightly harsher environment (primarily higher temperatures) than its predecessor and will operate for 150-hour missions.

- a. The observed reliabilities of the antenna and power supply can be used because they are for 150-hours, the length of a mission for the new system. However, since the environment is slightly harsher, the reliabilities are degraded by 5% to 0.93 and 0.87, respectively.
- b. The failure rate for the new signal processor is estimated using a conservative value for its predecessor of 3 failures per 10,000 hours. This value is adjusted to address the harsher environment by increasing it by 5% to 3.2

failures per 10,000 hours. Since a constant failure rate is being used, it is assumed that the underlying pdf is the exponential. The reliability of the new signal processor for 150-hours is estimated as $e^{-(0.00032 \times 150)} = 0.95$.

c. The old receiver transmitter has an MTBF of 5,000 hours, which is equivalent to a failure rate of 0.0002 failures per hour. We degrade this by 5% to account for the more severe environment and use a failure rate of 0.00021. The reliability of the modified receiver transmitter is $e^{-(0.00021 \times 150)} = 0.97$.

d. The reliability of the new system is estimated to be $0.93 \times 0.87 \times 0.95 \times 0.97 = 0.75$.

C-4. Stress-strength interference method

Figure C-2 shows the curves for the stress and strength distributions for a mechanical part used in a given application. In this case, both stress and strength are Normally distributed. For two Normal curves, the area of interference is called Z, the Standardized Normal Variant. If we have the values for the means and variances of the stress and strength, we can calculate Z and look up the probability (the area of interference) in probability tables.

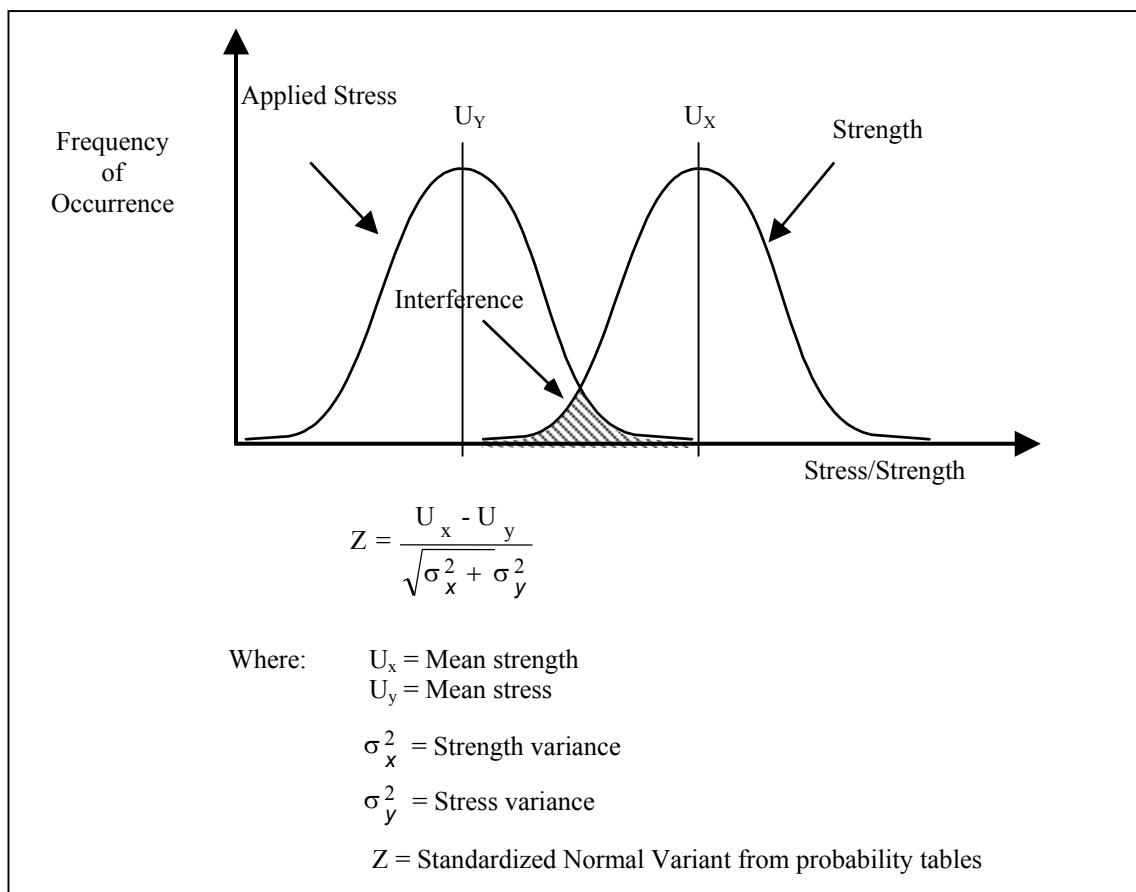


Figure C-2. Example of the stress-strength interference method when both stress and strength are Normally distributed.

a. Assume the mean strength is 50,000 psi and the variance of the strength distribution is 40,000 psi². Assume the mean stress is 30,000 psi and the variance of the stress distribution is 22,000 psi². Using these values, we calculate Z = 2.54.

b. From a probability table, we find that a value of 2.54 for Z corresponds to a probability of 0.00554, or 0.544% probability of failure (unreliability).

c. The reliability is $1 - \text{Interference} = 1 - 0.00554 = 0.99445$ or 99.445%.

C-5. Empirical model

Figure C-3 shows a spherical roller bearing that supports a rotating shaft. The empirical model for predicting the B_{10} fatigue life of bearings was given in table 3-1 and is shown again in figure C-3. Recall that the B_{10} life is the life at which 90% of a given type of bearing will survive.

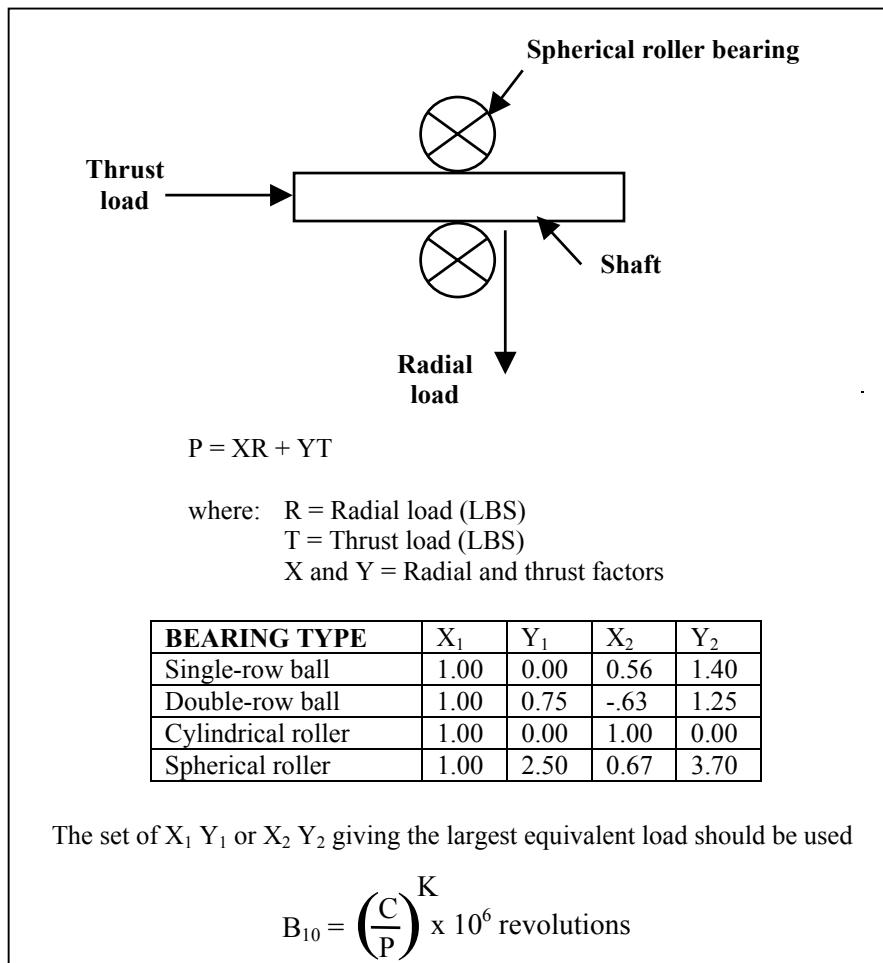


Figure C-3. Calculating the B_{10} life for a spherical roller bearing.

a. Assume that the radial load is 1,000 lbs. and the thrust load is 500 lbs. As stated in the figure, we calculate the resultant load, P, by first using the factors X₁ and Y₁ and then X₂ and Y₂ and using the largest result. For a spherical roller bearing, $P_1 = 1 \times 1,000 + 2.5 \times 500 = 2,250$, and $P_2 = 0.67 \times 1,000 + 3.7 \times 500 = 2,520$. The largest result of these two calculations, 2,520 lbs. will be used.

b. Recall that the values of C and K come from the bearing manufacturer's literature. For the example, K = 10/3 and C = 3,000 lbs. Substituting in the empirical bearing fatigue life equation, we find that the B_{10} life is 1.8 million revolutions.

C-6. Failure data analysis

In this example, we have tested 20 valves until all failed. The times to failure, in cycles, are shown in table C-1. We can use Weibull analysis to determine the reliability of the valves at any point in time (number of cycles); in this case, at 100 cycles. A variety of software packages are commercially available for performing Weibull analysis.

Using one of these software packages, Weibull++™ by ReliaSoft™ Corporation, we find that the reliability of this type of valve, when operated for 100 cycles is 90%. Figures C-4 and C-5 show the input page and graph for the analysis using the software.

Table C-1. Times to failure (cycles) for 20 valves

85	180	250	325
375	400	450	500
550	600	700	850
900	1000	1200	1300
1500	1900	2000	2550

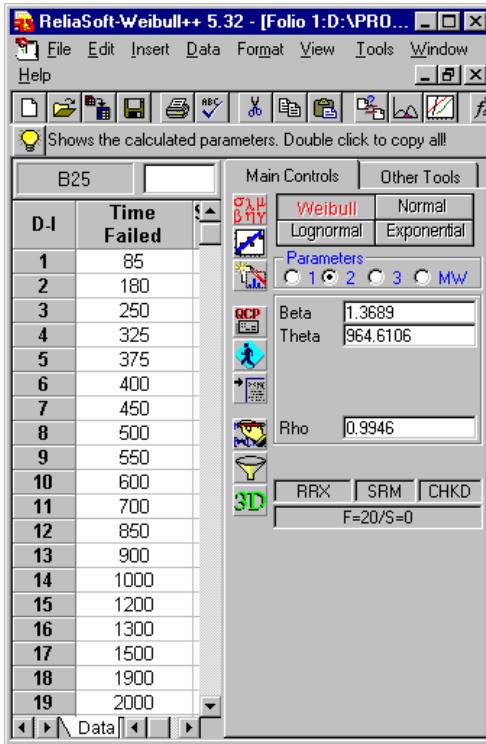


Figure C-4. Input page from Weibull++™ for failure data analysis example.

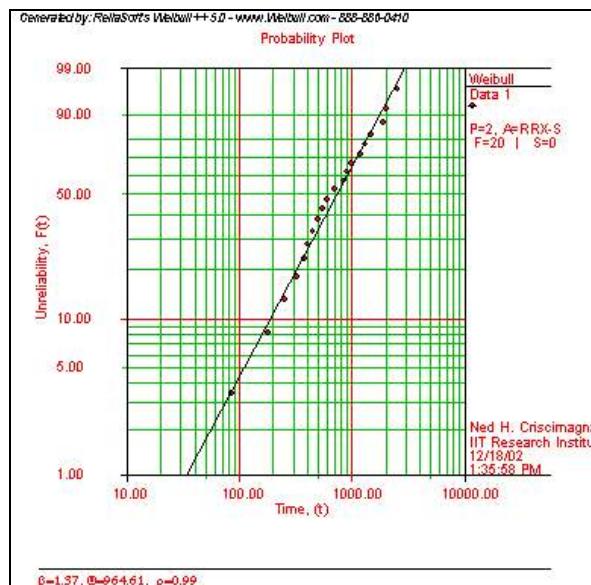


Figure C-5. Graph of Weibull plot from Weibull++TMfor data analysis example.